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HIGH PERFORMANCE "M5" FIBER FOR BALLISTICS / STRUCTURAL COMPOSITES

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ABSTRACT

The ballistic impact potential of M5 fiber-based armor systems is estimated using an "armor materials by design" model for personnel armor; the model is based on a dimensional analysis of the mechanical properties of the fibers used to construct the armor system. The model indicates that M5 fiber-based armor has the potential to substantially decrease the weight of body armor while enhancing or maintaining impact performance. Composite fragmentation armor systems were developed using less than optimal quality M5 fiber and tested under ballistic impact; the performance of these armor systems was exceptional.

1. INTRODUCTION

M5 fiber is a high performance fiber originally developed by Akzo Nobel and is currently produced by Magellan Systems International (Magellan). The M5 fiber used in this work was produced by Magellan using a batch process on bench-scale equipment. The equipment used in this work had several limitations. Among other things, problems associated with the inability to effectively de-gas the polymer dope prior to spinning created a situation where air bubbles had formed upstream of the spinneret.

Despite the fact that the ultimate mechanical properties of the available M5 fibers were lower than would have estimated to be required in order for the fiber to be a viable high performance ballistic protective material, it was decided to conduct ballistic impact tests to determine whether M5 had intrinsic limitations that might make the fiber unsuitable as a ballistic protective material.

2. M5 MECHANICAL PROPERTIES

The average mechanical properties of single fibers used in this work were: strength: 4 GPa, modulus: 271 GPa, elongation at break: 1.4%, and density: 1.7 g/cm^3. The strength of M5 used in this work was low compared to the goal mechanical properties of the fiber. The goal mechanical properties for M5 fiber are based on experience with the production of high performance fibers and on the predictions of a fiber physics model [Northolt and Baltussen, 2001. Among the important characteristics of the fiber are: a currently available average modulus of up to 333 GPa; expected yarn axial tensile modulus 400-450 GPa, currently available strength up to 8 GPa (best single fiber); expected average yarn axial tensile strength 9.5 GPa; currently available elongation at break up to 2.4%; expected average elongation 2.5%; axial compressive strength well in excess of PBO have already been demonstrated (1.7 GPa).

3. ARMOR PERFORMANCE MODEL

A set of dimensionless parameters for the optimization of textile-based body armor systems, was previously described by Cunniff, 1999. Results of the dimensional analysis indicate that the following dimensional groups are applicable to textile armor:

$$\Phi\left(\frac{V_{50}}{(U^*)^{1/3}}\ ,\ \frac{A_d A_p}{m_p}\right) = 0 \qquad (1)$$

- σ - Fiber ultimate axial tensile strength
- ε - Fiber ultimate tensile strain
- ρ - Fiber density
- E - Fiber modulus (assumed linearly elastic)
- A_p - Projectile presented area
- m_p - Projectile mass
- V_{50} - V50 ballistic limit
- A_d - System areal density
- U^* - the product of fiber specific toughness and strain wave velocity $U^* = \frac{\sigma\varepsilon}{2\rho}\sqrt{\frac{E}{\rho}}$

The dimensional analysis model allows for the estimation of the performance of an armor system based solely on the mechanical properties of the fibers that constitute the armor system. The results of the dimensional analysis for M5 are compared to several other fibers in Figure 1

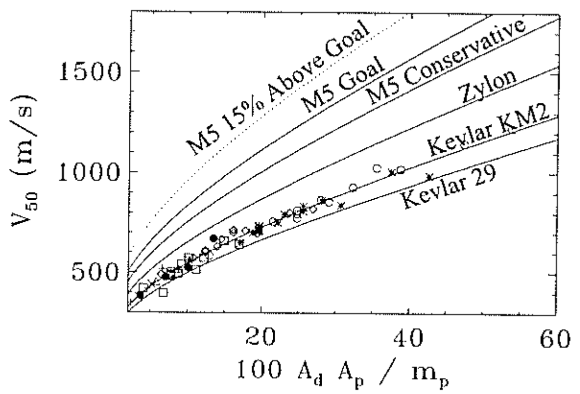

Fig. 1. Expected M5 performance compared to aramids and PBO

3. BALLISTIC TESTING RESULTS

V50 ballistic impact tests were conducted using 2-, 4-, and 16-grain right circular cylindrical steel projectiles. Results of the V50 tests are illustrated in Figure 2. In the Figure, V50 results for M5 composites are compared to similarly prepared Zylon composites. The performance of M5 is seen to be nearly comparable to the Zylon material.

The exceptional performance of M5 composites was unexpected; the performance, based on the dimensional analysis model, was expected to be slightly inferior to Kevlar 29 composites.

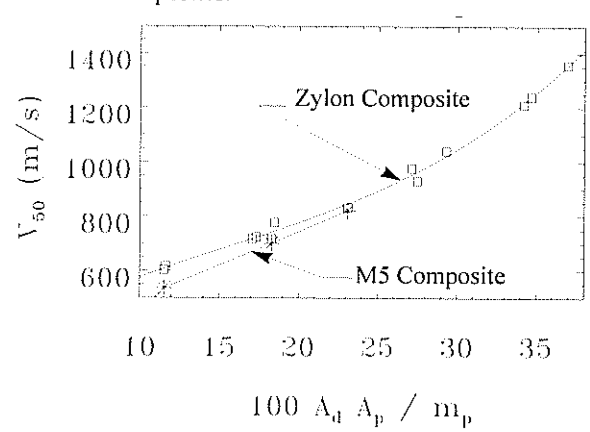

Fig. 2. Results of M5 Ballistic Testing.

In the model, it is assumed that lateral compressive forces on the fibers of a body armor system do not contribute to appreciable energy absorption or to premature failure of the system. Since lateral compressive stresses are quite localized, the former assumption appears to be reasonable, the latter assumption is expected to lead to discrepancies for some materials. It is possible (since M5 fibers are expected to be stiffer and stronger than aramids or PBO fibers in lateral compression) that they retain a larger fraction of the one-dimensional tensile strength than either aramids of PBO when subjected to combined lateral compression and axial tension during the impact event. Examination of the failure of M5 yarns near the impact point suggests that they are indeed less affected by compressive loadings.

4. SUMMARY

The ballistic impact performance of composite materials prepared from relatively inferior (3.9 GPa average ultimate tensile strength, 1.4% elongation at break, and 271 GPa initial modulus) M5 fiber were estimated using a dimensionless analysis model. These armor systems were estimated to preform at a level slightly inferior to aramid armor systems. However, M5 armor systems based on these fibers have been shown to provide performance almost as good as the best composite materials ever prepared for fragmentation protection. Based on these results, it is estimated that fragmentation protective armor systems based on M5 will reduce the areal density of the ballistic component of these systems by approximately 40-60% over Kevlar KM2 fabric at the same level of protection.

REFERENCES

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